# ATLANTIC TROPICAL SYSTEMS OF 1969

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## ABSTRACT

A census of Atlantic tropical systems of 1969 presents information on the history of each tropical wave or disturbance, including the dates these systems passed three key stations: Dakar, Barbados, and San Andrés Island.

## 1. INTRODUCTION

This is the third of an annual series of articles whose purpose is to tabulate and summarize the history of less intense tropical systems. For details on named storms during the 1969 hurricane season, the reader is referred to a companion article in this issue by Simpson, Sugg, and Staff (1970).

Tropical meteorologists have been interested in transitory perturbations in the pressure and wind field since Dunn (1940) first observed moving isobaric centers. Several attempts have been made to track tropical systems on their journeys across the Atlantic Ocean. For the most part, these have been unsuccessful because of data limitations. It was not until the weather satellite became an operational reality a few years ago that this endeavor became feasible. As our ability to interpret the satellite product in terms of dynamical processes improves, the fruits of this type of study will move closer to the truth. It is recognized that some of the results presented in these preliminary efforts may have to be altered; however, it is hoped that the initial facts will prove to be sufficiently accurate so as to provide a good foundation. Definitions were established in two previous articles by Simpson et al. (1968, 1969) and will not be repeated in detail. However, it is necessary to briefly reiterate the guidelines which undergird the basic philosophy used in arriving at the census to be presented. The primary interest is in synoptic scale perturbations in the wind and pressure fields; therefore, conventional data serve as the basic observing tool. Where possible, inferences are based entirely on these data. For example, the tracks of all systems in the Caribbean were based almost exclusively on upper air data from the network of island stations. In the tropical Atlantic, conventional data is almost nonexistent, and satellite pictures provide the only useful information. Fortunately, perturbations in the trades of the easterly wave type are frequently accompanied by an "inverted V" cloud pattern that is usually easy to recognize, making it possible to follow tropical waves across the vast data-void regions of the Atlantic. In the weaker systems where the cloud organization was not sufficient to verify an ocean crossing and no appropriate wind shift was observed at Barbados, it was assumed the wave dissipated over the ocean. When wind data in the Antilles Islands revealed the passage of a wave that could not be traced back to Africa, it was assumed the system developed in the Atlantic. In the tabulations to be presented, there was no attempt to eliminate weaker systems. Every wind shift that appeared

on the time sections for Dakar, Barbados, and San Andrés in the western Caribbean was interpreted to be a moving perturbation in the wind field.

The intertropical convergence zone (ITCZ) disturbances were more difficult to define and count. Conventional upper air data is practically nonexistent; therefore, our knowledge of moving disturbances in this extensive zone of low pressure is limited. Occasionally, the persistent east-west band of cloudiness that characterized the ITCZ is disrupted by a broad area of enhanced convection that can be tracked westward for several days. Heuristically, it seems logical to assume this is being caused by a synoptic scale perturbation in the wind field, even though it cannot be verified. We have attempted to track these features in the following way: At the National Hurricane Center, a disturbance has been defined as a migratory convective system that persists for at least 24 hr and covers an area of at least 100 to 300 sq mi. In this paper, an effort has been made to eliminate the more transitory systems by extending the minimum persistence time from 24 to 48 hr. It is recognized that this more conservative viewpoint excludes some systems that should rightfully be counted. The treatment of an ITCZ disturbance is one of the more unsatisfying aspects of our census.

Cold Lows in the upper troposphere have not been treated explicitly. The stronger ones whose influence extends downward to the lower troposphere have been counted indirectly as tropical waves. For example, both Kara and Gerda developed within the circulation of intense upper level cold Lows. Data limitations prohibit an accurate analysis of the complex upper tropospheric flow patterns during the summertime. Since most of the upper Lows are not associated with significant amounts of cloudiness, satellite information is not very useful in tracking this type of system. It is hoped that in the future we can expand our census to include this most intriguing tropical system.

## 2. CENSUS OF 1969 TROPICAL SYSTEMS

The results of the 1969 census are presented in tables 1 and 2 and figure 1. Table 1 gives selected pertinent information describing the history of each tropical wave or disturbance, including the dates the systems passed three key stations, Dakar, Barbados, and San Andrés in the western Caribbean. This information is summarized in table 2 and is shown schematically in figure 1.

There was a total of 111 independent systems in 1969, from which evolved 34 depressions and 13 named storms.

TABLE 1.—*Pertinent information summarizing the history of tropical waves and disturbances in 1969*

| Dakar passage | Nature | Weakened, Atlantic | Formed, Atlantic | Barbados passage | Nature | Weakened, Caribbean | Formed, Caribbean | San Andrés passage | Nature | Atlantic storm | Pacific storm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| June 1 | Wave | X | — | — | — | — | — | — | — | — | — |
| — | — | — | X | June 2 | ITCZ | X | — | — | — | — | — |
| June 4 | ITCZ | X | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | X | June 7 | Dep. | — | — |
| — | — | — | X | June 8 | Wave | X | — | — | — | — | — |
| — | — | — | — | — | — | — | X | June 12 | Wave | — | — |
| — | — | — | X | June 11 | Wave | — | — | June 16 | Wave | — | — |
| June 6 | Wave | — | — | June 15 | Wave | X | — | — | — | — | — |
| June 9 | Wave | — | — | June 17 | Wave | — | — | June 20 | Wave | — | — |
| — | — | — | X | June 20 | Wave | — | — | June 22 | Wave | — | — |
| June 10 | ITCZ | X | — | — | — | — | — | — | — | — | — |
| June 14 | Wave | — | — | June 21 | Wave | — | — | June 23 | Wave | — | — |
| June 16 | Wave | — | — | June 22 | Wave | — | — | June 25 | Wave | — | — |
| — | — | — | — | — | — | — | X | June 27 | ITCZ | — | — |
| — | — | — | — | — | — | — | X | June 29 | Wave | — | Ava |
| June 20 | Wave | — | — | June 27 | Wave | X | — | — | — | — | — |
| — | — | — | — | — | — | — | X | July 1 | ITCZ | — | — |
| June 22 | Wave | — | — | June 29 | Wave | X | X | July 2 | Wave | — | — |
| June 25 | Wave | X | — | — | — | — | — | — | — | — | — |
| June 27 | Wave | — | — | July 2 | Wave | X | — | — | — | — | — |
| — | — | — | — | — | — | — | X | July 6 | Wave | — | Bernice |
| July 2 | Wave | — | — | July 9 | Wave | — | — | July 11 | Wave | — | Claudia |
| — | ITCZ Mid-Atlantic | — | — | — | — | — | — | — | — | — | — |
| July 8 | Wave | — | — | July 15 | Wave | — | — | July 17 | Wave | — | — |
| July 11 | Wave | — | — | July 17 | Wave | — | — | July 21 | Wave | — | — |
| July 13 | Wave | — | — | July 19 | Wave | X | — | — | — | — | — |
| July 14 | Wave | X | — | — | — | — | — | — | — | — | — |
| July 16 | Wave | — | — | July 21 | Wave | — | — | July 24 | Wave | — | — |
| — | — | — | — | — | — | — | X | July 27 | Wave | — | — |
| July 19 | ITCZ | — | — | July 26 | Dep. | — | — | July 29 | Wave | — | — |
| July 20 | Wave | — | — | July 28 | Wave | — | — | July 30 | Wave | — | Doreen |
| July 22 | Wave | — | — | July 31 | Dep. | — | — | — | — | Anna | — |
| July 24 | Wave | X | — | — | — | — | — | — | — | — | — |
| July 26 | Wave | X | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | X | Aug. 1 | ITCZ | — | — |
| — | — | — | X | Aug. 2 | Wave | X | — | — | — | — | — |
| — | — | — | — | — | — | — | X | Aug. 4 | ITCZ | — | — |
| July 29 | Wave | — | — | Aug. 5 | Wave | — | — | Aug. 7 | Wave | — | — |
| July 31 | Wave | X | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | X | Aug. 8 | Dep. | — | — |
| — | — | — | — | — | — | — | X | Aug. 10 | ITCZ | — | — |
| Aug. 3 | Wave | — | — | Aug. 9 | Wave | — | — | — | — | Blanche | — |
| Aug. 5 | Wave | — | — | Aug. 10 | Wave | — | — | Aug. 14 | Dep. | Camille | — |
| Aug. 9 | Wave | — | — | Aug. 15 | Wave | X | — | — | — | — | — |
| Aug. 11 | Wave | — | — | Aug. 19 | Hur. | — | — | — | — | Debbie | — |
| — | — | — | — | — | — | — | X | Aug. 21 | Wave | — | — |
| Aug. 13 | ITCZ | X | — | — | — | — | — | — | — | — | — |
| Aug. 15 | Wave | — | — | Aug. 21 | Wave | — | — | Aug. 24 | Wave | — | Florence |
| — | — | — | X | Aug. 24 | ITCZ | X | — | — | — | — | — |
| Aug. 16 | Wave | — | — | Aug. 25 | Wave | — | — | Aug. 27 | — | — | — |
| Aug. 19 | Wave | X | — | — | — | — | — | — | — | — | — |
| — | — | — | X | Aug. 26 | Dep. | X | — | — | — | — | — |
| — | ITCZ Mid-Atlantic | — | — | — | — | — | — | — | — | — | — |
| — | ITCZ Mid-Atlantic | — | — | — | — | — | — | — | — | — | — |
| Aug. 20 | Dep. | — | — | Aug. 28 | Wave | — | — | Sept. 1 | Storm | Francelia | Glenda |
| Aug. 24 | Dep. | X | — | — | — | — | — | — | — | — | — |
| Aug. 27 | Wave | — | — | Sept. 4 | Wave | — | — | Sept. 6 | Wave | — | — |
| Aug. 28 | Wave | X | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | X | Sept. 7 | ITCZ | ⊙ | Heather |
| Aug. 30 | Wave | — | — | Sept. 7 | Wave | X | — | — | — | — | — |
| Sept. 1 | Wave | — | — | Sept. 8 | Wave | — | — | Sept. 11 | Wave | — | — |
| Sept. 3 | ITCZ | X | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | X | Sept. 14 | ITCZ | — | — |
| Sept. 5 | Dep. | — | — | Sept. 12 | Dep. | — | — | Sept. 15 | Wave | — | — |
| — | — | — | — | — | — | — | X | Sept. 17 | ITCZ | — | — |
| — | — | — | X | Sept. 15 | Wave | — | — | Sept. 20 | Wave | — | — |
| — | — | — | — | — | — | — | X | Sept. 21 | Wave | — | Irah |
| Sept. 8 | Wave | — | — | Sept. 19 | Wave | X | — | — | — | Holly | — |
| Sept. 10 | Wave | X | — | — | — | — | — | — | — | — | — |
| Sept. 14 | Wave | — | — | Sept. 24 | Dep. | — | — | — | — | Inga | — |
| Sept. 16 | Wave | X | — | — | — | — | — | — | — | — | — |
| Sept. 18 | ITCZ | X | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | X | Sept. 25 | ITCZ | — | — |
| Sept. 20 | Wave | — | — | Sept. 29 | Wave | X | — | — | — | — | — |
| Sept. 25 | ITCZ | — | — | Oct. 2 | ITCZ | X | — | — | — | — | — |
| Sept. 26 | Wave | X | — | — | — | — | — | — | — | — | — |
| Sept. 28 | Wave | X | — | — | — | — | — | — | — | — | — |
| Oct. 1 | Wave | X | — | — | — | — | — | — | — | — | — |
| Oct. 2 | Wave | X | — | — | — | — | — | — | — | — | — |
| Oct. 3 | Wave | X | — | — | — | — | — | — | — | — | — |
| Oct. 8 | Wave | X | — | — | — | — | — | — | — | — | — |
| — | — | — | X | Oct. 10 | Wave | X | — | — | — | — | — |

TABLE 1.—Continued

| Dakar passage | Nature | Weakened, Atlantic | Formed, Atlantic | Barbados passage | Nature | Weakened, Caribbean | Formed, Caribbean | San Andrés passage | Nature | Atlantic storm | Pacific storm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | — | — | X | Oct. 12 | ITCZ | — | — |
| — | — | — | — | — | — | — | X | Oct. 14 | Dep. | Laurie | — |
| Oct. 11 | ITCZ | — | — | Oct. 17 | Wave | — | — | Oct. 20 | Wave | — | — |
| Oct. 14 | ITCZ | — | — | Oct. 20 | ITCZ | — | — | Oct. 22 | ITCZ | — | — |
| Oct. 18 | Wave | X | — | — | — | — | — | — | — | — | — |
| Oct. 20 | Wave | X | — | — | — | — | — | — | — | — | — |
| — | — | — | X | Oct. 21 | Wave | X | — | — | — | — | — |
| — | — | — | — | — | — | — | X | Oct. 27 | ITCZ | — | — |
| — | — | — | X | Oct. 27 | ITCZ | X | — | — | — | — | — |

TABLE 2.—*Number of tropical systems that formed in various geographical areas in 1969. The numbers in parentheses indicate systems that were counted in a weaker stage.*

| Systems | Africa | Tropical Atlantic | Subtropical Atlantic | Caribbean | Gulf | Total independent systems |
|---|---|---|---|---|---|---|
| Waves | 47 | 7 | 0 | 6 | 0 | 60 |
| ITCZ Disturbances | 8 | 6 | — | 11 | 0 | 25 |
| Depressions | 3 | 1 (6) | 10 (1) | 6 (2) | 5 | 25 (9) |
| Storms (named) | 0 | (4) | (4) | 1 (4) | 0 | 1 (12) |
| Totals | 58 | 14 (10) | 10 (5) | 24 (6) | 5 | 111 (21) |

The numbers in parentheses in table 2 indicate systems that were counted in a less intense state. For example, eight depressions formed in the Caribbean, but two of these developed within the circulation of tropical waves whose origin was in Africa. The depression tracks are presented in figure 2. Six of the 34 depressions occurred prior to June; thus, during the hurricane season which officially extends from June 1 to November 30, there were 28 depressions and 105 tropical systems.

To facilitate comparison, the Atlantic and adjacent areas have been subdivided into five regions: Africa, the tropical Atlantic south of 20° N. latitude, the subtropical Atlantic north of 20° N., the Caribbean, and the Gulf of Mexico. Table 2, which stratifies the systems by type and region of formation, reveals two important results. First, approximately one-half (58) of the systems originated over Africa, whereas nearly one-quarter developed in the Caribbean. The latter were mainly ITCZ developments just north of the Canal Zone, and the African systems were primarily perturbations in the trade-wind belt. Second, over 50 percent of the systems were of the tropical wave type.

Over one-half of the African systems (33) maintained their identity as far west as the Lesser Antilles, whereas 25 weakened in the tropical Atlantic. Eleven systems formed over the Atlantic, combining with the 33 from Africa, thus producing 44 systems in the Antilles. Of these 44 systems, 23 crossed the Caribbean, 17 weakened, and 20 formed; thus, 43 moved into the eastern Pacific from the Atlantic. Three ITCZ disturbances were tracked for several days in the tropical Atlantic before dissipating.
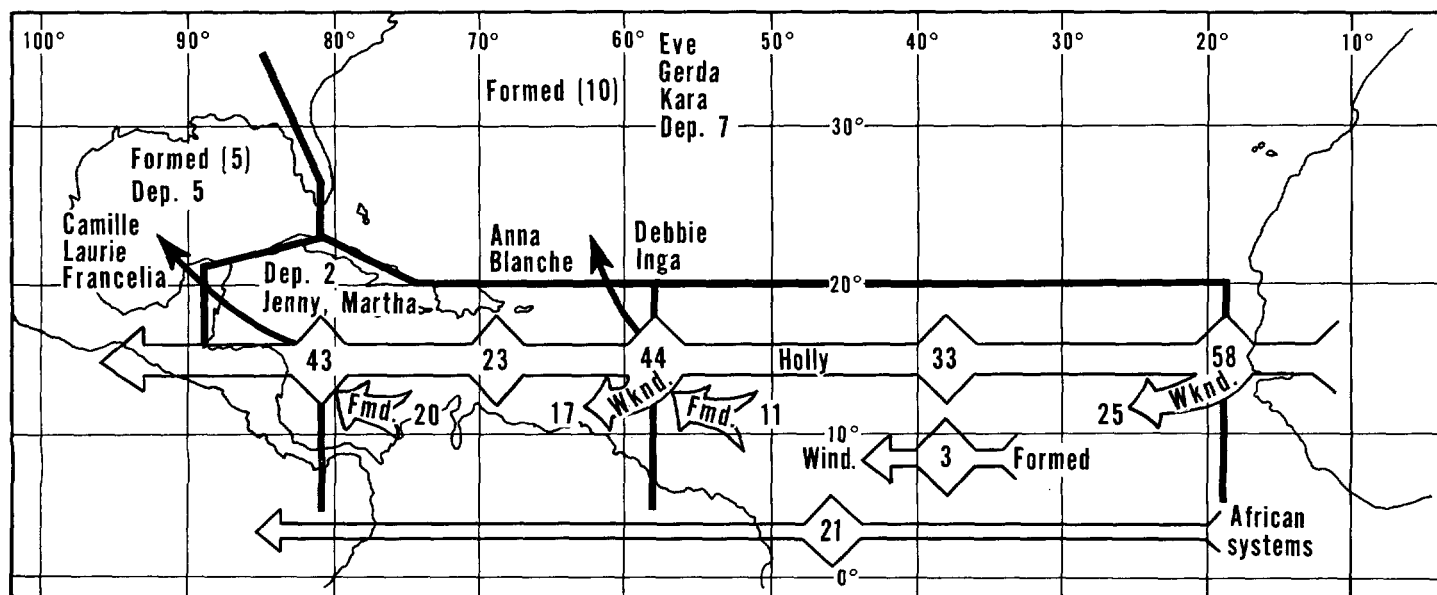


FIGURE 1.—Summary of the synoptic scale tropical systems observed from western Africa to the eastern Pacific during 1969. The large numerals indicate the number of systems passing five areas, the west coast of Africa, the mid-Atlantic Ocean, the Lesser Antilles, the Caribbean, and Central America.
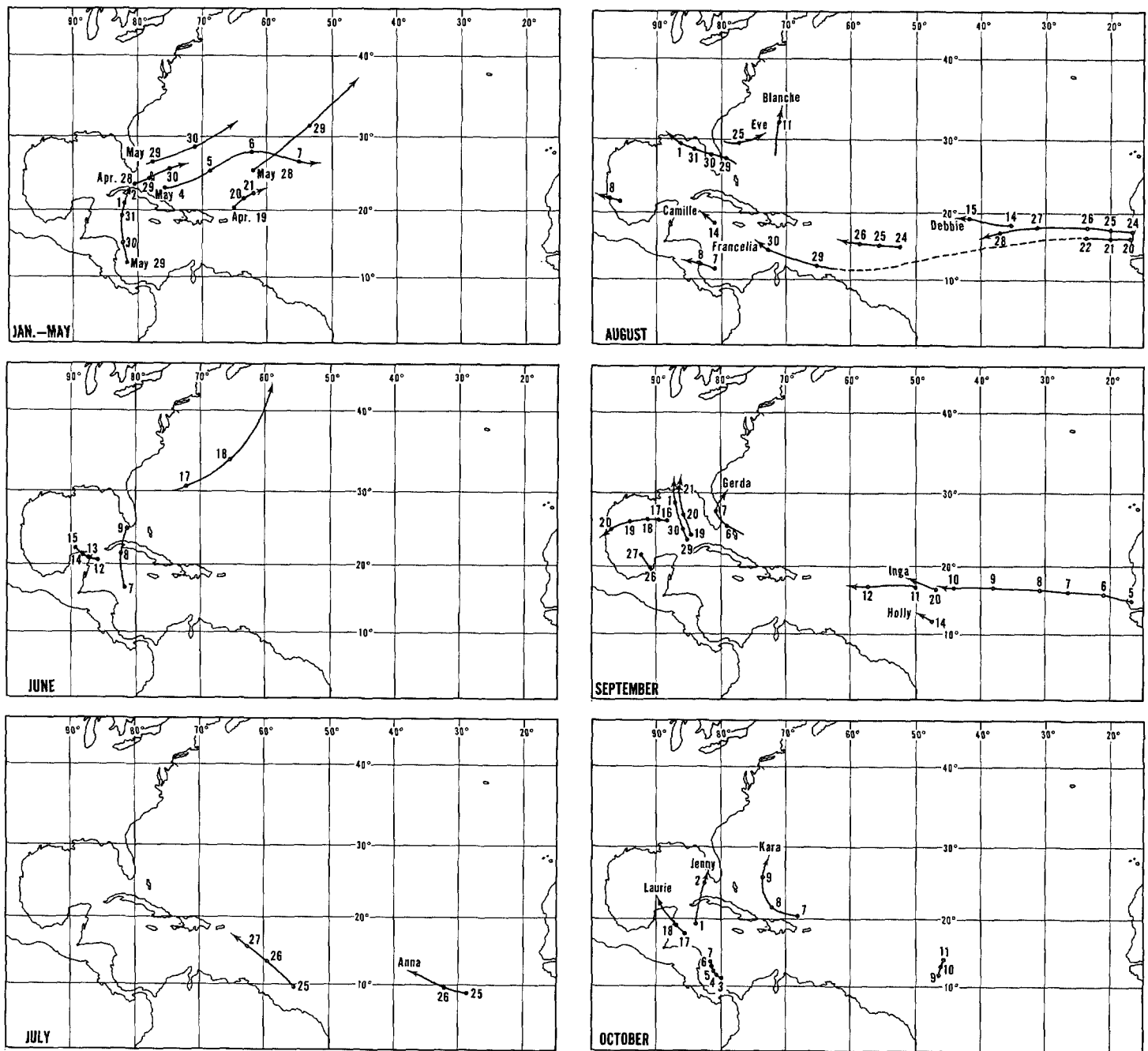
FIGURE 2.—Tracks of tropical depressions in 1969.

Seven depressions and three storms (Eve, Gerda, and Kara) formed in the subtropical Atlantic, five depressions formed in the Gulf of Mexico, and two depressions and two storms (Jenny and Martha) developed in the Caribbean. Anna, Blanche, Camille, Debbie, Francelia, Holly, and Inga were triggered by tropical waves from Africa, and one of the depressions that formed in the northwest Caribbean intensified into Laurie after moving into the Gulf of Mexico.

Atlantic systems initiated most of the eastern Pacific storms in 1969. Figure 3 summarizes their role in cyclogenesis off the west coast of Mexico. Of the 43 systems crossing Central America, 26 were tropical waves, five were depressions, and 11 were ITCZ disturbances. One, Francelia, was a full-fledged hurricane when it moved into Guatemala.

Over the eastern Pacific Ocean, Claudia, Doreen, Florence, and Glenda were triggered by African impulses. Disturbances that formed in the Caribbean initiated Ava, Bernice, Irah, and Heather. Only two storms, Emily and Jennifer, developed over the Pacific; and of these, Emily formed within a temporale, over southern Mexico, that occurred in the wake of hurricane Camille. Thus, Jennifer was the only eastern Pacific storm not directly or indirectly related to Atlantic systems. Glenda actually resulted from a regeneration of Francelia which, in turn, was initiated by an African system. This system has the distinction of being labeled with five different designations before finally dissipating in the central Pacific. In both the Atlantic and eastern Pacific, a numbering system is used operationally to identify depressions. The system under discussion emerged from Africa as a depression and was designated
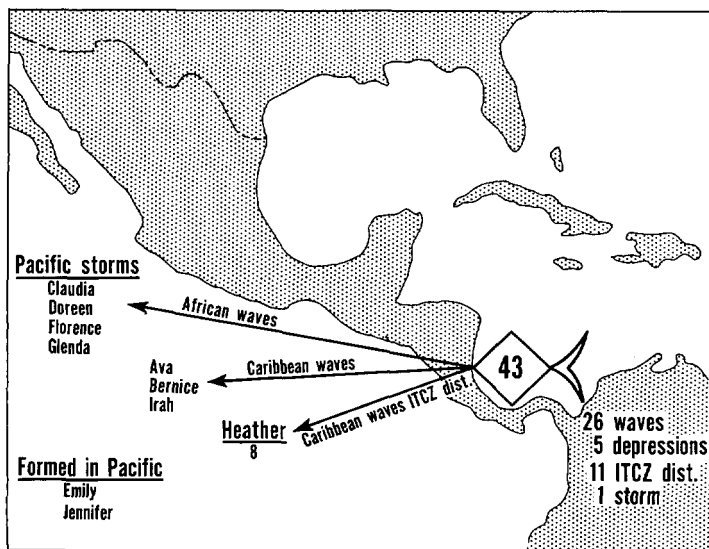
FIGURE 3.—Origin of tropical systems that initiated east Pacific storms in 1969.

TABLE 3.—*Comparison of the tropical systems that occurred during the hurricane seasons of 1968 and 1969*

|  | 1968 | 1969 |
|---|---|---|
| Total systems, all types | 107 | 105 |
| Dakar systems | 57 | 58 |
| Barbados systems | 59 | 44 |
| San Andrés systems | 28 | 43 |
| Depressions | 19 | 28 |
| Named storms | 7 | 13 |

number 20. Depression 20 weakened in the vicinity of the Cape Verde Islands and continued westward across the Atlantic as a tropical wave. Cyclogenesis initiated by this wave produced depression number 24 in the eastern Caribbean and Francelia in the western Caribbean. The remnants of Francelia became depression 10 and storm Glenda in the eastern Pacific.

It is interesting to note that nearly one-third of the African systems were tracked all the way to the Pacific.

## 3. COMPARISON OF 1969 WITH OTHER YEARS

This is the third year in which we have attempted to track all tropical systems in the Atlantic; however, some procedural changes between 1967 and 1968 limit direct comparisons, for the most part, to the last 2 yr, 1968 and 1969. Table 3 compares the census for these 2 yr. Even though there was considerable difference in the amount of tropical storm activity, the total number of tropical systems in 1968 and 1969 was remarkably similar. This means that the smaller number of depressions and named storms in 1968 cannot be explained as a reduction in the overall number of potential disturbances. Greater insight into this difference can be gained by comparing the number of depressions by month for the years 1967 through 1969, table 4. The major contribution to the smaller number in 1968 was the lack of depressions during August, which is

TABLE 4.—*Number of depressions that formed by month during the hurricane seasons of 1967, 1968, and 1969*

| Month | 1967 | 1968 | 1969 |
|---|---|---|---|
| June | 4 | 4 | 3 |
| July | 2 | 2 | 2 |
| Aug. | 7 | 3 | 10 |
| Sept. | 6 | 7 | 8 |
| Oct. | 10 | 2 | 5 |
| Total | 29 | 18 | 28 |

normally a month of maximum activity for east Atlantic and African disturbances. Posey (1967), Andrews (1968), and Dickson (1969) show that the August flow pattern over the subtropical Atlantic at 700 mb in 1968 was dominated by negative geopotential height anomalies in contrast to a more normal picture in 1969 and above-normal heights in 1967. Simpson et al. (1969) suggest this intrusion of westerlies over the subtropics in 1968 and associated weakening of the semipermanent Bermuda ridge were probably accompanied by a larger than normal vertical shear of the horizontal wind, a condition unfavorable for development of hurricanes according to Gray (1968). It appears that the main inhibiting factor for tropical cyclogenesis is related more to the prevailing circulation features, rather than to a lack of potential hurricane disturbances.

## 4. ORIGIN OF TROPICAL SYSTEMS

One of the major goals of the continuing effort to document these less intense systems is to gain a better understanding of tropical disturbances as they relate to the hurricane problem. It is now possible to make tentative inferences based on 2 yr and, in some cases, 3 yr of record. Before presenting these results, it is necessary to clarify terminology to avoid problems in semantics. The systems responsible for tropical cyclogenesis may be divided into one of two broad categories according to the main source of energy: (1) Those drawing primarily on latent heat and, (2) those feeding mainly on a baroclinic source of energy. It is not always possible to assign a particular system to one of these categories because often both sources of energy are active. Regardless of the nature of the initiating system, intensification to storm or hurricane strength is always accompanied by a dominance of latent heat and establishment of a warm core. Within this general framework, there are five main types of tropical systems that have a bearing on the hurricane problem. Systems relying mainly on latent heat include:

1) ITCZ disturbances in both the Atlantic and Caribbean.

2) Non-ITCZ disturbances resulting from enhanced regions of convection. These are typical of developments during the late spring and early fall in the western Caribbean.

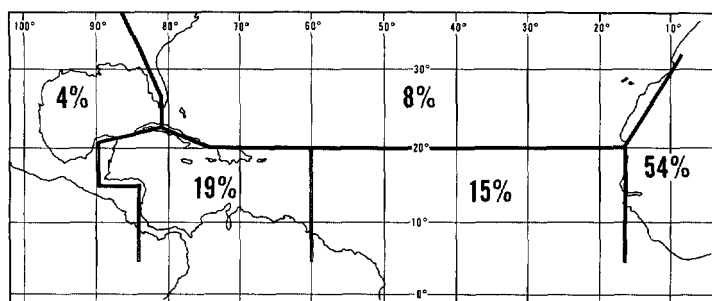3) Tropical waves (also listed in this group, although their energy source is not clearly understood).

FIGURE 4.—Percentage of Atlantic tropical systems that formed in various geographical areas during the hurricane seasons of 1968 and 1969.

TABLE 5.—*Summary of the systems that initiated Atlantic-named storms and depressions during the years 1967, 1968, and 1969. The systems have been divided into two categories, tropical and baroclinic, depending on their source of energy.*

| | Tropical | | Baroclinic | | |
| Years | African systems | Disturbances | Upper Lows | Lower Lows | Totals |
|---|---|---|---|---|---|
| | | Named storms | | | |
| 1967 | 4 | 3 | 0 | 1 | 8 |
| 1968 | 2 | 3 | 1 | 1 | 7 |
| 1969 | 7 | 3 | 2 | 1 | 13 |
| Totals | 13 | 9 | 3 | 3 | 28 |
| | | Depressions | | | |
| 1967 | 15 | 5 | 4 | 5 | 29 |
| 1968 | 8 | 5 | 3 | 3 | 19 |
| 1969 | 11 | 8 | 3 | 6 | 28 |
| Totals | 34 | 18 | 10 | 14 | 76 |

Baroclinic systems are generally of two main types:

1) Upper cold Lows—occasionally an upper tropospheric cold Low will intensify and extend its influence downward in the vertical to the surface where a Low may form.

2) Lower Lows—the second group forms on weak baroclinic zones that in general were originally associated with fronts. This type of development is usually initiated by an approaching upper trough in the westerlies.

Even though the initial impulse feeds mainly on a baroclinic field, convection is generally triggered and if the convection becomes concentrated, the release of latent heat may quickly destroy the original baroclinic field, thus changing the nature of the system from cold to warm core. The baroclinic development sequence is not the most common method of generating a hurricane and accounts for only a relatively small number of tropical storms each year, mainly those forming over the subtropical Atlantic and, to a lesser extent, the Gulf of Mexico.

Figure 4 shows the percentage of tropical systems that formed in five different geographic areas during the hurricane seasons of 1968 and 1969. The percentages are based on a 2-yr total of 212 systems. Over half of the systems originated over, or to the east of, Africa. If we assume all of the systems over the subtropical Atlantic
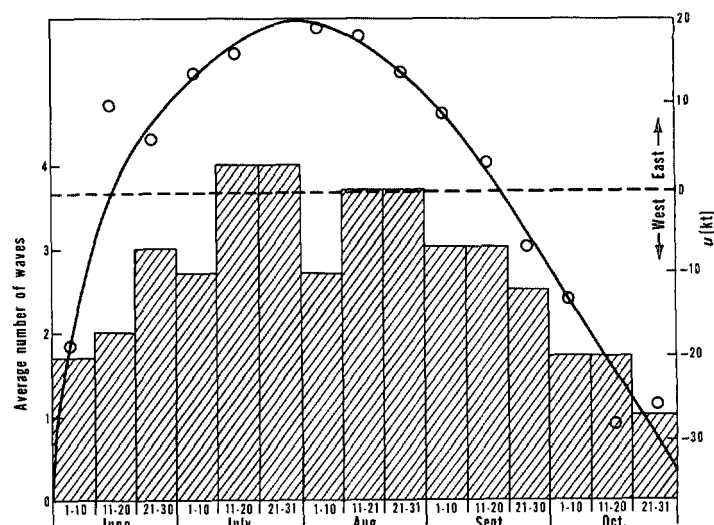


FIGURE 5.—Comparison of the average number of easterly waves passing Dakar with the zonal component of the 200-mb winds at Dakar per 10-day periods for the 3 yr, 1967, 1968, and 1969.

and Gulf of Mexico were initiated by baroclinic processes, a fact that is not true, we see this type of development accounts for, at the most, less than 15 percent of the total systems.

Table 5 summarizes the type of systems that were responsible for the depressions and named storms during the 3-yr period of 1967 to 1969. The most striking result shows that African systems account for approximately 45 percent of both the named storms and depressions. The baroclinic process was responsible for 32 percent of the depressions and 21 percent of the named storms. Half of the depressions that were initiated by tropical disturbances became named storms (nine of 18) while only one-fourth (six of 24) of the baroclinic depressions deepened. This difference is not surprising, since cold-core systems present a greater obstacle to the hurricane process.

Summarizing the past 2 yr, one of every 10 systems became a named storm, and one of five became a depression. On the average, one of every three depressions became a named storm.

In the eastern Pacific, 29 named storms formed during 1968 and 1969. Two were initiated by waves having their origin in the Atlantic, three by Caribbean waves, and six by ITCZ disturbances that formed in the Caribbean north of the Canal Zone. Only seven formed in the ITCZ in the Pacific. Eleven of the 29, or nearly 40 percent, were triggered by African waves. Thus, we see that African systems play a prominent role in the development of both Atlantic and east Pacific storms.

Before closing this section, we would like to comment briefly on the origin of African waves. These remarks will be directed to perturbations in the trade-wind belt and are not applicable to ITCZ disturbances. Carlson (1969) attempted to track the African waves back to their point of origin by performing a daily analysis over west Africa during the summer of 1968. His analysis extended eastward to 20° E. longitude. He found that most of the waves moved into the area of analysis from the east, and

concluded they probably form over the mountains of east Africa. This conclusion is in agreement with Thompson (1965) who states that moving perturbations play no part in the weather of east Africa.

African waves are a summertime phenomena. During the past 3 yr, the first wave occurred in June and the last in October. This suggests they may be related to the strong subtropical easterly jet stream that dominates the upper troposphere of west Africa during the summer. This relationship was examined by comparing the average number of waves per 10-day periods that passed Dakar during the past 3 yr for the period June 1 to October 30, with the 3-yr mean zonal component of the 200-mb wind at Dakar for the same 10-day periods. The results are shown in figure 5. The wave frequency reaches a peak value of four per 10 days or one every 2.5 days in late July at precisely the same time the zonal component of the 200-mb wind assumes a maximum value from the east of 20 kt. African waves begin appearing with the onset of the easterlies in the upper troposphere and become more frequent as the strengths of the easterlies increase. In the fall when the upper easterlies disappear, wave activity ceases. It is interesting to note that east Africa is the only place in the Tropics where the summer subtropical easterly jet traverses a perpendicularly oriented mountain chain. Perturbations in the trade-wind belt occur just downstream from this mountain range.

## 5. CLOUD CLUSTERS

The problem of explaining and understanding cloud clusters is commanding a great deal of attention in tropical meteorology today. For example, the last phase of project BOMEX addressed itself to this problem, and the Joint Organizing Committee for GARP (Global Atmospheric Research Program) in planning for the first tropical experiment has given the cloud-cluster problem top priority. Our attention was focused on these features by the satellite, even though, prior to the satellite era, conventional observations occasionally revealed unexplained weather conditions that existed for only a day or two. As viewed by the satellite, there often appears to be little continuity in the clusters from day to day. In extreme cases, bright cloud masses covering areas several hundreds of miles across appear one day and are gone the next. Cloud clusters frequently are not persistent and at times appeared to be distributed at random. This led many people to question the reality of conservative, moving weather systems in the Tropics and to minimize the role of synoptic scale perturbations in the wind and pressure field, an attitude that continues in some circles today. Since disturbance tracks were not available; it was impossible to verify or refute this position. The tracks determined in this study permit an evaluation of this premise for the first time. Daily digitized satellite mosaics serve as the basic data source. Cloud clusters were identified on these charts each day, and the location of the geometric center of the cloud mass was determined. To be considered, a minimum diameter of 3° latitude was required with a cloud cover greater than 50 percent.



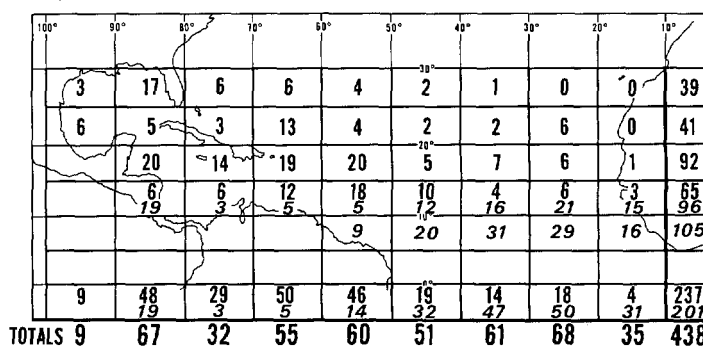| 100° | 90° | 80° | 70° | 60° | 50° | 40° | 30° | 20° | 10° | |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 17 | 6 | 6 | 4 | 2 | 1 | 0 | 0 | | 39 |
| 6 | 5 | 3 | 13 | 4 | 2 | 2 | 6 | 0 | | 41 |
| | 20 | 14 | 19 | 20 | 5 | 7 | 6 | 1 | | 92 |
| | 6/19 | 6/3 | 12/5 | 18/5 | 10/12 | 4/16 | 6/21 | 3/15 | | 65/96 |
| | | | | 9 | 20 | 31 | 29 | 16 | | 105 |
| 9 | 48/19 | 29/3 | 50/5 | 46/14 | 19/32 | 14/47 | 18/50 | 4/31 | | 237/201 |
| TOTALS 9 | 67 | 32 | 55 | 60 | 51 | 61 | 68 | 35 | | 438 |

FIGURE 6.—Number of cloud clusters per 5° latitude by 10° longitude areas for the 3 mo of July, August, and September 1969. Upright numerals represent non-ITCZ clusters, and slanted numerals indicate ITCZ clusters.

There were no minimum restrictions imposed on the time duration of the cluster. Since only one picture was considered each day, this automatically eliminated systems whose duration was only a few hours and that occurred between pictures. To minimize the inclusion of clusters associated with baroclinic systems in the westerlies, the investigation was restricted to an area south of 30° N. and limited to the months of July, August, and September 1969.

Figure 6 shows the geographical distribution of the clusters for the 3-mo period in 5° latitude by 10° longitude areas. The latitudinal and longitudinal variations are summarized along the bottom and right sides of the figure. The clusters have been tabulated in two categories; slanted figures indicate ITCZ clusters, and straight figures have been used for non-ITCZ clusters. There were a total of 438 clusters, 237 non-ITCZ and 201 ITCZ, or a daily average of between two and three of each type.

Non-ITCZ clusters were most frequent between 15° and 20° N. and longitudinally between 50° and 70° W., with a primary maximum in the vicinity of the Lesser Antilles Islands. Frank (1968) found that easterly waves and upper tropospheric cold Lows tend to couple in this area, producing a temporary enhancement of cloudiness or "cloud blowup." This maximum reflects this process. The ITCZ is more active in the eastern Atlantic than in the western portion. A ·secondary maximum of ITCZ activity is noted in the western Caribbean north of the Canal Zone.

The persistence of each cluster was determined, and the results are shown in figure 7. The average and median lifetime of both ITCZ and non-ITCZ clusters was between 1 and 2 days. The 438 clusters represent 175 different cloud-cluster systems. Less than one-third of the clusters persisted for more than 2 days, confirming early observations that clusters were not conservative.

The main purpose in examining the cloud clusters was to determine the relationship of clusters to synoptic scale systems in the wind and pressure fields. A cluster was assumed to be related to a system if the geometric center of the cloud mass was within 300 mi of a wave axis or the center of a circulation. Table 6 summarizes the results for each month; 384, or nearly 90 percent of the clusters,
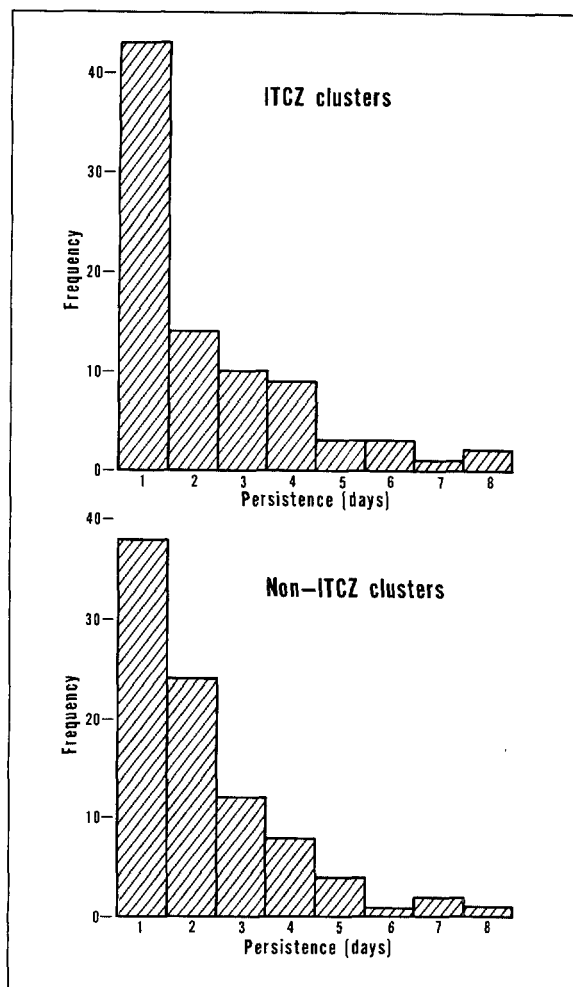
FIGURE 7.—Frequency distribution of the persistence of ITCZ and non-ITCZ cloud clusters during July, August, and September 1969.

TABLE 6.—*Summary of the cloud clusters that were, and were not, associated with tropical systems during July, August, and September 1969*

| Type of system | July | Aug. | Sept. | Totals |
|---|---|---|---|---|
| Clusters associated with tropical systems | | | | |
| Named storms | 5 | 12 | 14 | 31 |
| Depressions | 5 | 21 | 24 | 50 |
| Upper cold Lows | 8 | 6 | 4 | 18 |
| Baroclinic lower Lows | 8 | 5 | 5 | 18 |
| ITCZ disturbances | 25 | 18 | 28 | 71 |
| Easterly waves | 73 | 70 | 53 | 196 |
| Clusters not associated with tropical systems | | | | |
| ITCZ | 11 | 15 | 11 | 37 |
| Non-ITCZ | 1 | 5 | 11 | 17 |
| Totals | 136 | 152 | 150 | 438 |

were associated with synoptic systems, and only 54 could not be directly related to an apparent circulation feature. Of the 54 clusters, 37 were located along the ITCZ where data limitations make it almost impossible to identify disturbances in the wind field. It is very likely that some of these clusters were associated with synoptic disturbances in the ITCZ. We conclude that cloud clusters are directly related to synoptic systems and not randomly distributed. Even though cloudiness associated with synoptic systems is not conservative from day to day, the synoptic system provides a favorable setting for the growth of mesoscale processes associated with cloud clusters. To understand cloud clusters, one must also understand the nature of the synoptic system.

## ACKNOWLEDGMENT

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